The Brenner Challenge - TBMs versus Drill & Blast in High Cover Conditions

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ABSTRACT: The tunneling industry is abuzz about the upcoming Brenner Base Tunnel Project. The tunnel route will run below the Alps with a maximum cover of 1,600 m. In such conditions, choosing the right tunneling method requires much forethought. Geology in high cover tunnels is often complex and TBM excavation often proves to be the optimal solution versus traditional methods like drill & blast. Both excavation methods are considered for this project. TBMs have proven themselves in deep tunnels worldwide, and are often faster, safer and more cost-effective than their conventional counterparts, as well as more customizable. This paper will explore the advantages of mechanical excavation and the best types of TBMs for the Brenner Base Tunnel Project, a comparison of mechanical excavation versus drill & blast, and important considerations for ground support in high cover conditions. A case study of the high-cover Olmos Trans-Andean Tunnel will also be presented.

1 PROJECT BACKGROUND

1.1 About the Brenner Base Tunnel

The oft-mentioned Brenner Base Tunnel will become the longest underground structure in the world. The 64 km long tunnel will run from Tulfes/Innsbruck, Austria to Fortezza, Italy, making it arguably one of the longest—if not the longest—underground railway tunnels in the world. The tunnel route is a challenging one, traveling below the Brenner Pass in the Alps mountain range with a maximum cover of around 1,600 m. When complete in 2026, twin 8.1 m i.d. tubes will run single-track trains just 70 m apart from one another, connected every 333 m by cross passages.

Excavation on the massive scale required to build the Brenner Base Tunnel necessitates customized machinery, skilled crews, and precision planning. Besides the challenges of variable rock types, groundwater and high overburden towards the center of the alignment, it will be prudent to plan for rock bursting and squeezing conditions.

The route also crosses a major fault zone where the European and Adriatic tectonic plates press together. These anticipated conditions gave rise to the practical need for an exploratory tunnel, which will provide additional design and programming data for the excavation of the main tubes. Once completed, the exploratory tunnel will be used for drainage during construction and eventually as the service tunnel during operation. The exploratory tunnel could also carry power and data cables.

Excavation of the exploratory tunnel has been challenging, and was divided into multiple contracts, some still yet to start. Geology along the alignment comprises zones of quartz phyllite, Bundner slates (containing dolomites, quartzites, anhydrites, greywacke sandstone and other slates), gneiss, and Brixner granites. The so-called Periadriatic Line or tectonic plate boundary at the 47-48km mark is a zone of particular concern.

The exploratory tunnel utilized a 6.3 m diameter double shield TBM. The drive was inaugurated in spring 2008 and was expected to finish in about 20 months in early 2010. Advance, however, was slow. In August 2009, a stretch of the tunnel lining through a fault zone more than 6 km into the drive suffered damage from groundwater pressures of up to 27 bar. Recovery works required ground stabilization, removal of deformed and damaged rings, polymer injection for part of the affected stretch and installation of steel rings along the length and a little beyond the fault zone. The shielded TBM restarted in December 2009 and in just under a year, in September 2010, holed through into a dismantling cavern at the junction of tunnel and adit to successfully complete the works (see Figure 1). More sections of exploratory tunnel are in the works, and are variously planned as both TBM and Drill & Blast operations.

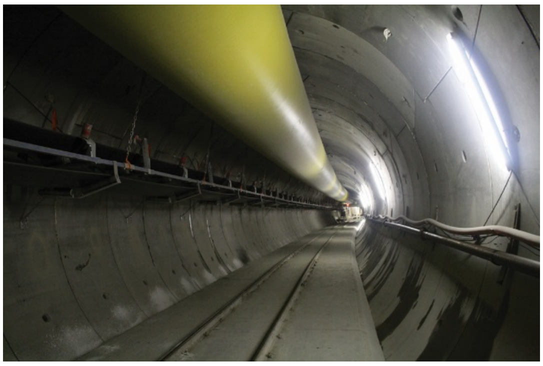

Figure 1. Completed exploratory tunnel.

2 CHOOSING THE EXCAVATION METHOD

2.1 Mechanical Excavation Versus Drill and Blast

For the main tubes of the Brenner Base Tunnel, ground conditions may prove similar or slightly different—it can be difficult to predict the character of the rock in a mountainous tunnel under high rock cover, even with information collected from the exploratory tunnel. When one considers the machine type required for such varied unknown conditions, many factors need to be evaluated such as machine versatility and investigational methods like continuous probe drilling and pre-grouting. Encountering high water pressure is much safer and arguably easier to control from within a TBM rather than in a drill & blast operation.

A tunnel boring machine combines multiple concurrent operations that in drill & blast would be sequential. These operations include advancing, ground support, and muck excavation, all occurring simultaneously. With modern TBMs, ground support such as the McNally Roof Support System can be used to allow lining to be extruded from the machine as it advances—a very safe option.

In addition it has been shown through multiple examples that TBM tunnels are driven at least two to three times faster than drill & blast tunnels even with significant stretches of unstable ground. In any tunnel over a few km in length, the longer lead time for a TBM is negated by its faster advance rates, making it the most efficient method. Given the length of the Brenner Base Tunnel and the necessity for quick, cost effective, and most importantly safe excavation, TBMs could very well be ideal.

Last but not least, one has to realize that specifically when headings run into fault zones and disturbed ground formations, the energetic impact from drill & blast operations will cause even more disturbance to the rock strata as well as complications. Tunnel boring with a TBM enables permanent and fine control of the energy introduced to the rock strata and it is limited to the face.

2.2 Comparison of Hard Rock TBM Types

2.2.1 Main Beam TBMs

In even the most extreme ground conditions, Main Beam TBMs (also known as “open-type” machines) can be preferable to their shielded counterparts. Features such as open access behind the cutterhead for ground support and consolidation, unrestricted probe drilling, and the absence of a shield are all-important attributes in extreme conditions. In ground exhibiting squeezing-convergence and rock bursting, open-type machines often are better than shielded machines, as they are less likely to get stuck. They can also utilize the McNally Support System (see Figure 2), in which the curved finger shield plates are replaced for a curved assembly of pockets with rectangular cross-sections. In swelling-slacking ground Main Beam TBMs also allow for immediate ground treatment behind or over the top of the cutterhead. Open-type machines are capable of operating in ground with occasional to continuous water as long as a mitigation strategy combining grouting to stem flows, as well as pumps to remove the water, is employed.

Figure 2. Detailed view of the McNally Support system.

2.2.2 Shielded Hard Rock TBMs

Most shielded TBMs line the tunnel either simultaneous with or directly after a TBM stroke, resulting in an earlier useable date for the tunnel. Shielded machines also have the very beneficial advantage of providing a limited section of non-heavy support; i.e., the distance from the cutterhead to the grouted lining. Shielded TBMs can also have difficulty in faulted rock, as the working area for ground consolidation can somewhat restrict good face coverage TBMs. There are two types of shielded hard rock TBMs: Single Shield and Double Shield.

Single Shield TBMs are shorter in length and can therefore be launched from a shorter starter tunnel, and are typically utilized in non-self-supporting rock, as the machine advances by reacting against the concrete tunnel lining rather than unstable tunnel walls. They have the disadvantage of not having grippers, which allow greater pull, thrust and jogging of the cutterhead.

Double Shield TBMs are ideal in self-supporting rock, and some non-self-supporting rock, or in combination ground since they can react against either tunnel walls or segments. The shield also provides protection from rock falls and other problems, making it ideal in hard, blocky ground as well. In addition, in squeezing ground Double Shield TBMs can be used with compressible material as backfill or special segments to accommodate squeezing conditions.

3 ADVANCEMENTS IN GROUND SUPPORT

3.1 Squeezing/Convergent Ground

For squeezing or converging ground, over-boring is often necessary. The only practical solution to over boring is to pre-mount extra gage housing in the periphery of the cutterhead. In the over-bore zone, yielding type structures should be erected. These structures can include yielding steel arches, steel arches in conjunction with yielding jacks, shotcrete structures with yielding rock anchors, or combinations of the above supports. Such support needs to be placed with assistance of the ring beam erector or some other mechanical means. The most desirable location to place such support is immediately behind the cutterhead—a problematic situation with a shield type machine. The machines also must be equipped with very high torque to overcome the squeezing effect (see Figure 3).

Figure 3. Ground support for squeezing/convergent ground.

3.1.1 Rock Bursting

In rock bursting conditions wire mesh with rock bolts, yielding rock anchors, steel arches, ring beams or combinations of all of the above may be required. Such support can be placed with rock drills, a ring beam erector, and a shotcrete system. It is important to hold the rock in place to control and limit the disturbance of the rock to as great an extent as possible. Rock bursting could also be contained with TBMs in association with special lining (see Figure 4).

Figure 4. Example of rock bursting.

With modern TBMs, ground support such as the McNally Roof Support System can be used to allow lining to be extruded from the machine as it advances—a very safe option in these conditions. Today's TBMs are also equipped with all of the same tools and techniques that are used in drill & blast operations to excavate through difficult rock conditions. With sophisticated probing techniques installed on the TBM, the operator can predict what is ahead of the tunneling operation more quickly than drill & blast and react appropriately.

3.2 Swelling/Slacking Ground

In swelling and slacking conditions an effective ground treatment is shotcrete applied immediately behind the cutterhead. In extreme conditions, over-boring may be required and measures for rock support in squeezing ground may be needed. The support can be a combination of shotcrete, rock drills and ring beam erectors. The difficult question, however, is to predict the extent of swelling and squeezing. This is a very important consideration when considering the use of concrete segments in such conditions. Because of the difficulty of predicting the extent of swelling, two-pass lining systems have been used such as in the large diameter Niagara Tunnel Project in sedimentary rock. This large diameter (14.4 m) tunnel utilized initial ground support followed by a slipform concrete liner and a waterproof membrane (see Figures 5-6).


Figures 5-6. Swelling/slacking and squeezing/convergent ground.

3.3 Fault Zones & Water Pressure

Fault zones can be the most difficult condition to encounter, especially when associated with water under pressure. They are also the most difficult conditions for predicting expected advance rates.

In all conditions, advance probe drilling is recommended 30 to 40 meters in advance of the face with a 10 m overlay. This is especially important when fault zones or water are expected. When a fault zone or water is encountered, the extent of the zone should be explored prior to TBM boring within 10 – 20 meters of the zone. Drilling should be done on a 360 degree basis. First, the zone should be grouted to stop water inflows. After grouting, ground consolidation additives should be injected into the unstable rock or soil material. It may be necessary to inject such material into the face at short intervals of 2 to 4 meters, and advance at shorter intervals. The support of geologists experienced in predicting and treating fault zones, and of ground conditioning experts, is highly recommended when fault zones are encountered.

For passing through fault zones, grout and ground conditioning holes are required. After ground treatment, ground support such as spiling or fore poling through the front shield over the cutterhead may be necessary for safe and predictable advance. It is preferable to carry on this drilling as close to the face as possible to ensure good face coverage.

3.4 Blocky or Jointed Rock

In blocky or highly jointed rock, the McNally system to hold the rock in place has been proven very effective. If the rocks are held in place then this can prevent or lessen the condition of cathedralling over the cutterhead and fallout in front of the face; it will also reduce cutterhead damage. The ground support should be placed as close as possible to the cutterhead. Rock supports for the McNally system can be prefabricated rebar, wood/metal slats, or wire mesh in conjunction with rock straps and rock bolts (see Figures 7-8).

Figures 7-8. Blocky/jointing conditions.

4 CASE HISTORY: OLMOS TRANS-ANDEAN TUNNEL

A good example of a TBM boring through high cover conditions is Peru's Olmos Trans-Andean Tunnel. The tunnel is the second deepest civil works tunnel in the world after AlpTransit—below 2,000 m of Andean rock. The project, which provides a freshwater conduit to drought-ridden areas on the Pacific Ocean Watershed, languished for decades following multiple failed drill & blast attempts from both sides of the mountain range. The volcanic rock types, from quartz porphyry to andesite and dacite, were so complex and squeezing ground so severe that this type of tunneling was foregone.

In 2006, it was decided to attempt the project again using a tunnel boring machine. A Robbins 5.3 m diameter Main Beam TBM was used to excavate the remaining 12.8 km of tunneling. About 4 km into the excavation the TBM began to experience significant squeezing ground and severe rock bursting conditions. In order to keep tunneling, a plan was devised that involved in-tunnel machine modifications. The machine's roof shield fingers, which were being damaged by falling rock and rock bursting, were removed and replaced with the McNally Support System using steel slats. As mentioned above, the system allows the slats to be extruded from a series of pockets in the roof shield (and side support if needed), forming a continuous lining. The system allowed safe advance in the extreme rock bursting conditions and the machine was able to make a successful breakthrough in December 2011, following about 16,000 recorded rock bursting events. This is just one example of how a TBM can be adapted, even while in the tunnel, to excavate challenging conditions.

5 CONCLUSIONS

The Brenner Base Tunnel will be a challenge, no doubt. With the nearly endless iterations towards customization of tunnel boring machines in difficult ground, and customizable ground support methods, however, the excavation can be made safe and efficient. Main Beam (open-type) machines offer increased flexibility of probe drilling and grouting as well as ground support, making them a possible front runner for the tunnel. They are capable of excavating in squeezing, rock bursting, and faulted ground conditions with less likelihood of becoming stuck, and generally excavate faster than shielded TBMs. If the tunnel must be lined, however, Double Shield machines are still a good choice when used with compressible backfill and/or segments and overboring, so they do not become stuck in difficult ground.

The Brenner Tunnel is another engineering challenge for our industry, and when it is complete it will be a marvel—a testament to what human ingenuity and perseverance can build. Tunnel boring machines are sure to play a large part in that.